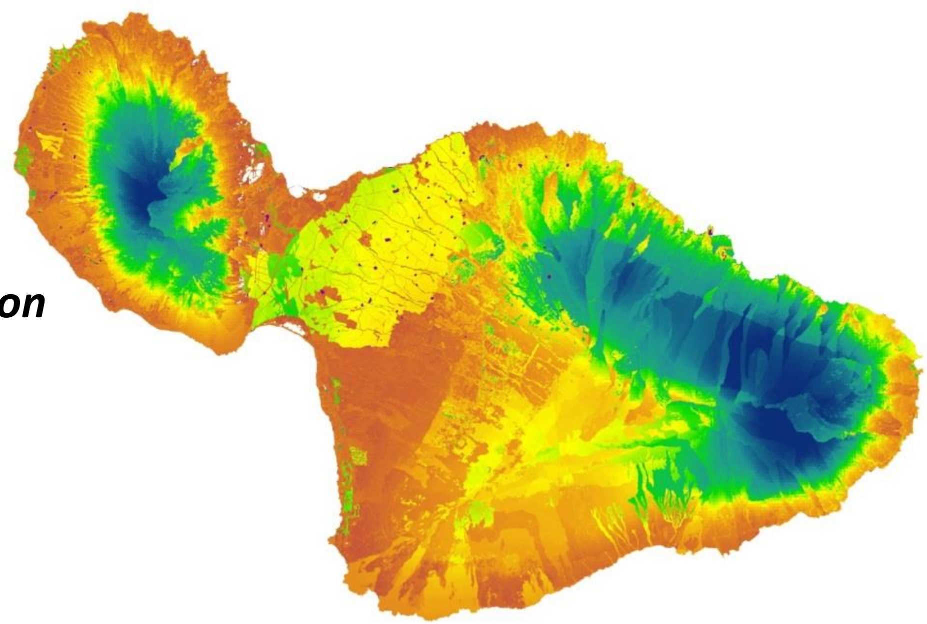
Estimating Climate-Change Impacts on Groundwater Recharge for the Island of Maui, Hawai‘i

Alan Mair

Pacific Islands Water Science Center



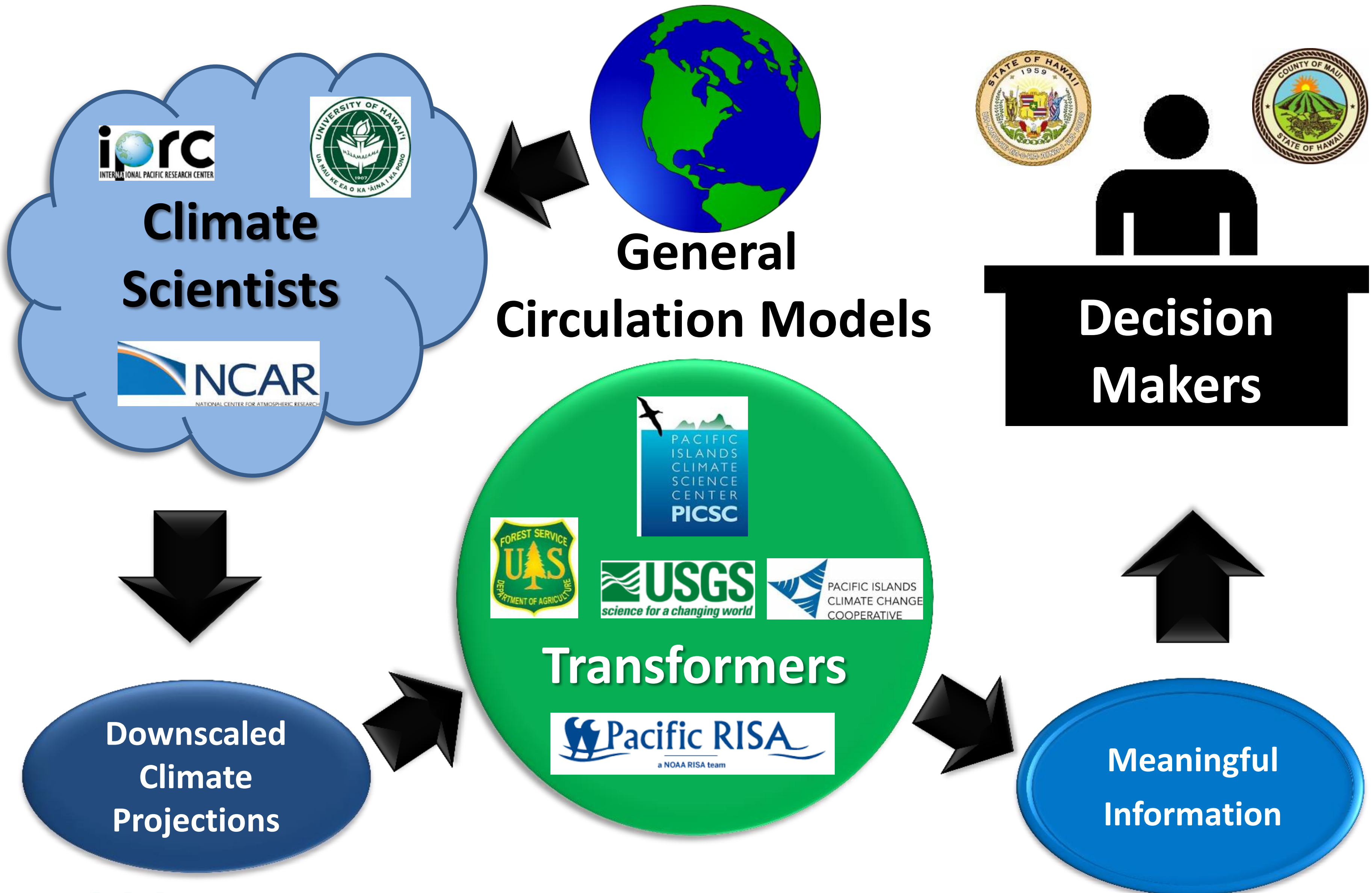
Meeting of the State of Hawai‘i Commission on Water Resource Management

Honolulu, Hawai‘i

July 20, 2016

U.S. Department of the Interior
U.S. Geological Survey

Flow of Downscaled Climate Information



Objectives

- Estimate spatial distribution of groundwater recharge for projected future climate conditions
  - Groundwater recharge is critical input to groundwater models used to assess groundwater availability
  - Groundwater recharge is used by State of Hawai‘i, Commission on Water Resource Management to compute sustainable yield
- Quantify differences in groundwater-recharge estimates between control (current) climate and future climate

Average Projected Changes for Maui

Component	Projected Dry Climate	Projected Wet Climate
Rainfall (climate models)	***-20%***	***+20%***
Recharge	***-21%***	***+21%***

- Available rainfall projections indicate either wetter or drier future
- Estimates of groundwater recharge are heavily dependent upon projected rainfall
- Areas of general agreement do exist – leeward areas get drier

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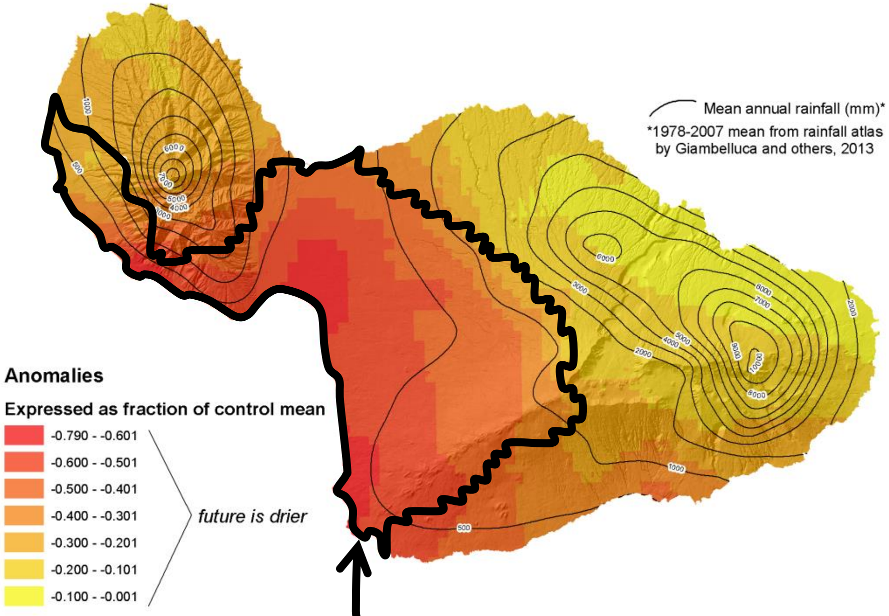
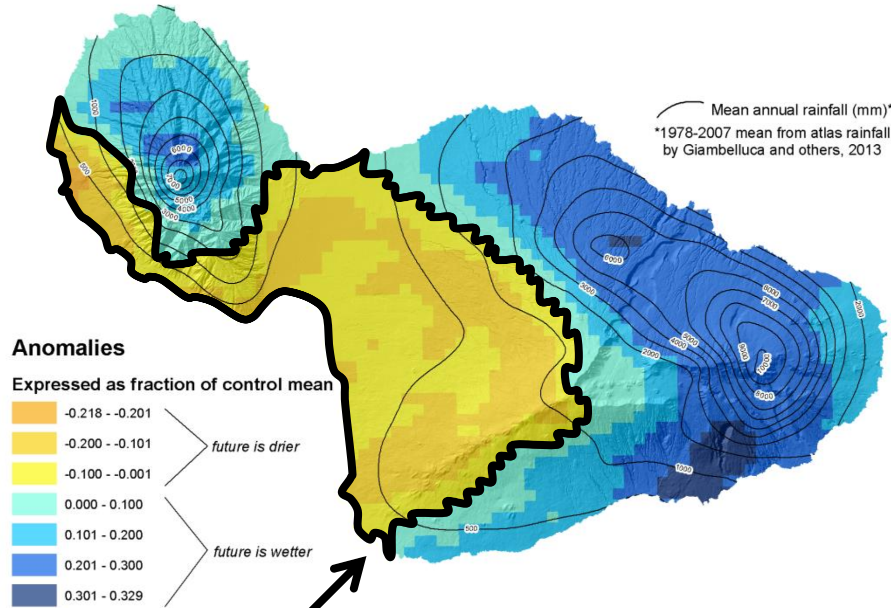
Selected Future Climate Scenarios

Projected
"Dry" Climate Scenario
Statistical Approach
RCP8.5, 2071-99



Projected
"Wet" Climate Scenario
Dynamical Approach
SRES A1B, 2080-99



Area of general agreement

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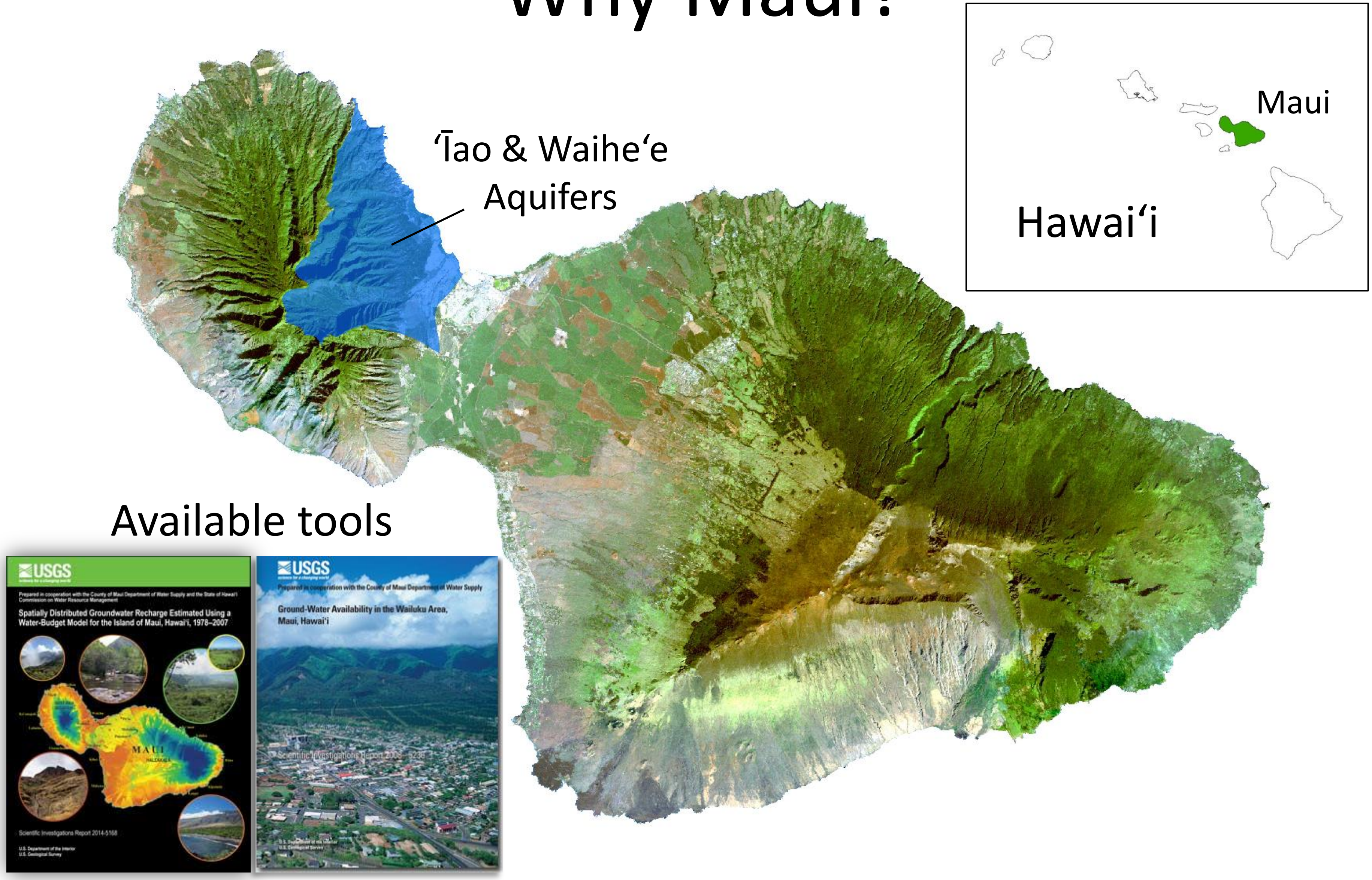
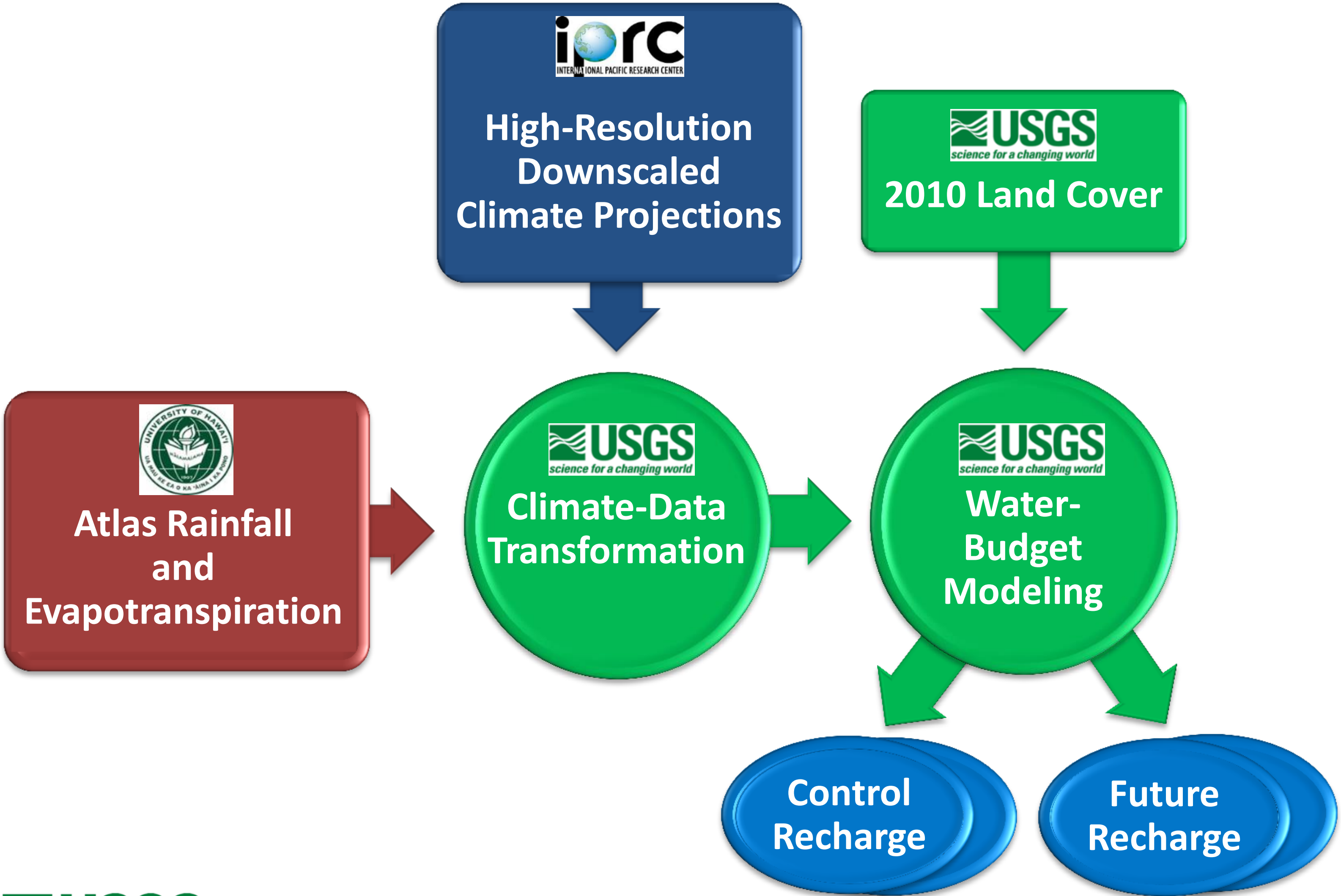
Why Maui?

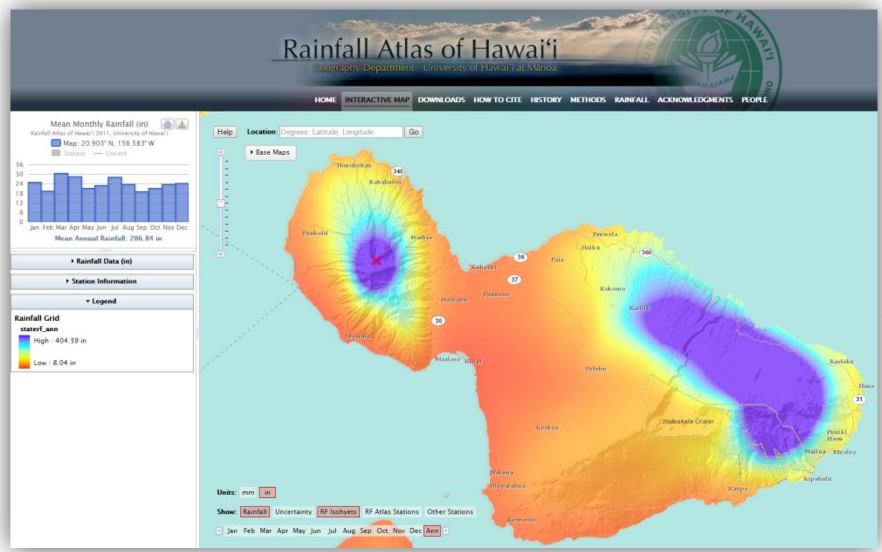


Available tools

Water-Budget Modeling Framework



Atlas Rainfall and Evapotranspiration



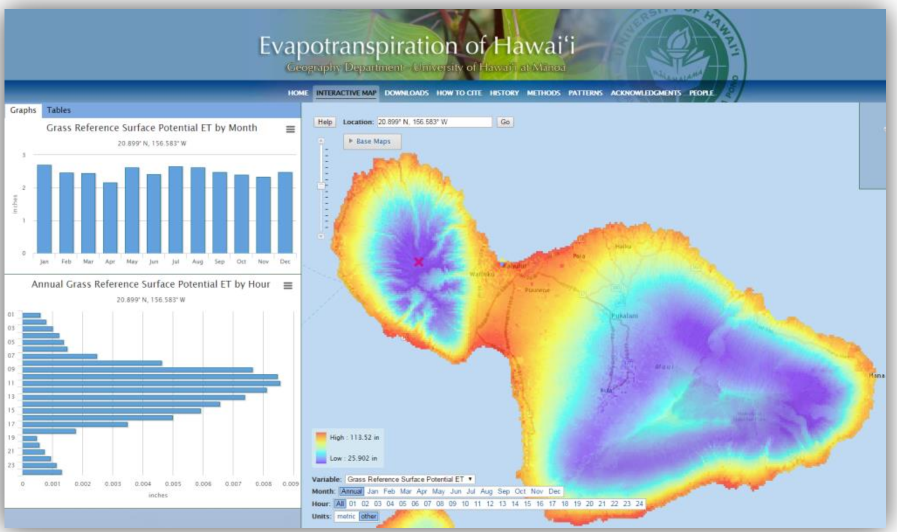
http://rainfall.geography.hawaii.edu/

Rainfall

- Interpolated maps of monthly rainfall during 1978-2009
- Daily rain-gage data for synthesizing daily rainfall

Evapotranspiration (ET)

- Interpolated maps of mean monthly reference ET for grass



http://evapotranspiration.geography.hawaii.edu/

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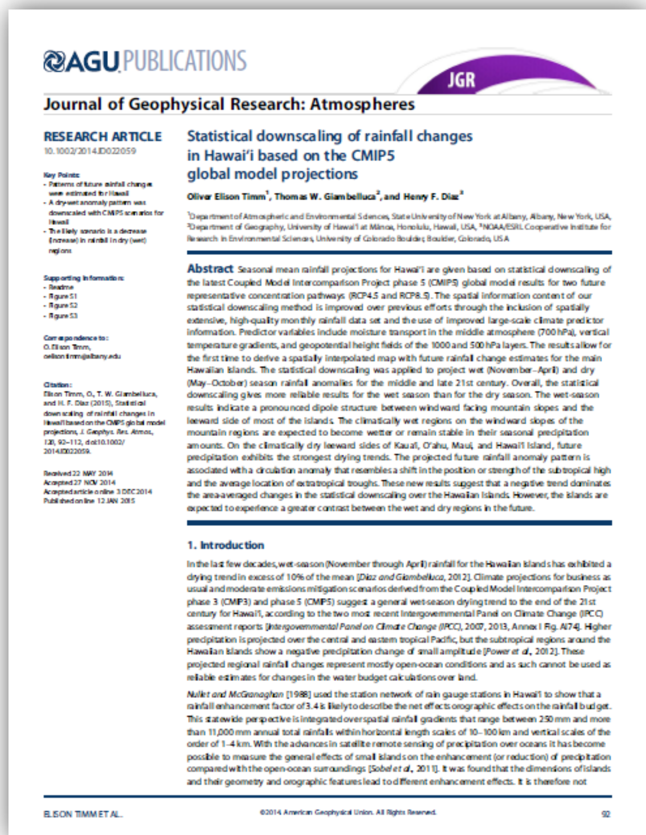
High-Resolution Downscaled Climate Projections

Statistical Approach



AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE

10.1002/2014JD022059

Key Points:
- Patterns of future rainfall changes were estimated for Hawaii
- A dry-wet anomaly pattern was downscaled with CMIP5 scenarios for Hawaii
- The likely scenario is a decrease (increase) in rainfall in dry (wet) regions

Supporting Information:
- Readme
- Figure S1
- Figure S2
- Figure S3

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Citation:
Elison Timm, O., T. W. Giambelluca, and H. F. Diaz (2015), Statistical downscaling of rainfall changes in Hawai'i based on the CMIP5 global model projections, J. Geophys. Res. Atmos., 120, 92–112, doi:10.1002/2014JD022059.

Received 22 MAY 2014
Accepted 27 NOV 2014
Accepted article online 3 DEC 2014
Published online 12 JAN 2015

Statistical downscaling of rainfall changes in Hawai'i based on the CMIP5 global model projections

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Abstract Seasonal mean rainfall projections for Hawai'i are given based on statistical downscaling of the latest Coupled Model Intercomparison Project phase 5 (CMIP5) global model results for two future representative concentration pathways (RCP4.5 and RCP8.5). The spatial information content of our statistical downscaling method is improved over previous efforts through the inclusion of spatially extensive, high-quality monthly rainfall data set and the use of improved large-scale climate predictor information. Predictor variables include moisture transport in the middle atmosphere (700 hPa), vertical temperature gradients, and geopotential height fields of the 1000 and 500 hPa layers. The results allow for the first time to derive a spatially interpolated map with future rainfall change estimates for the main Hawaiian Islands. The statistical downscaling was applied to project wet (November–April) and dry (May–October) season rainfall anomalies for the middle and late 21st century. Overall, the statistical downscaling gives more reliable results for the wet season than for the dry season. The wet-season results indicate a pronounced dipole structure between windward facing mountain slopes and the leeward side of most of the islands. The climatically wet regions on the windward slopes of the mountain regions are expected to become wetter or remain stable in their seasonal precipitation amounts. On the climatically dry leeward sides of Kaua'i, O'ahu, Maui, and Hawai'i Island, future precipitation exhibits the strongest drying trends. The projected future rainfall anomaly pattern is associated with a circulation anomaly that resembles a shift in the position or strength of the subtropical high and the average location of extratropical troughs. These new results suggest that a negative trend dominates the area-averaged changes in the statistical downscaling over the Hawaiian Islands. However, the islands are expected to experience a greater contrast between the wet and dry regions in the future.

1. Introduction

In the last few decades, wet-season (November through April) rainfall for the Hawaiian Islands has exhibited a drying trend in excess of 10% of the mean [*Diaz and Giambelluca*, 2012]. Climate projections for business as usual and moderate emissions mitigation scenarios derived from the Coupled Model Intercomparison Project phase 3 (CMIP3) and phase 5 (CMIP5) suggest a general wet-season drying trend to the end of the 21st century for Hawai'i, according to the two most recent Intergovernmental Panel on Climate Change (IPCC) assessment reports [*Intergovernmental Panel on Climate Change (IPCC)*, 2007, 2013, Annex I Fig. AI74]. Higher precipitation is projected over the central and eastern tropical Pacific, but the subtropical regions around the Hawaiian Islands show a negative precipitation change of small amplitude [*Power et al.*, 2012]. These projected regional rainfall changes represent mostly open-ocean conditions and as such cannot be used as reliable estimates for changes in the water budget calculations over land.

Nullet and McGranaghan [1988] used the station network of rain gauge stations in Hawai'i to show that a rainfall enhancement factor of 3.4 is likely to describe the net effects orographic effects on the rainfall budget. This statewide perspective is integrated over spatial rainfall gradients that range between 250 mm and more than 11,000 mm annual total rainfalls within horizontal length scales of 10–100 km and vertical scales of the order of 1–4 km. With the advances in satellite remote sensing of precipitation over oceans it has become possible to measure the general effects of small islands on the enhancement (or reduction) of precipitation compared with the open-ocean surroundings [*Sobel et al.*, 2011]. It was found that the dimensions of islands and their geometry and orographic features lead to different enhancement effects. It is therefore not

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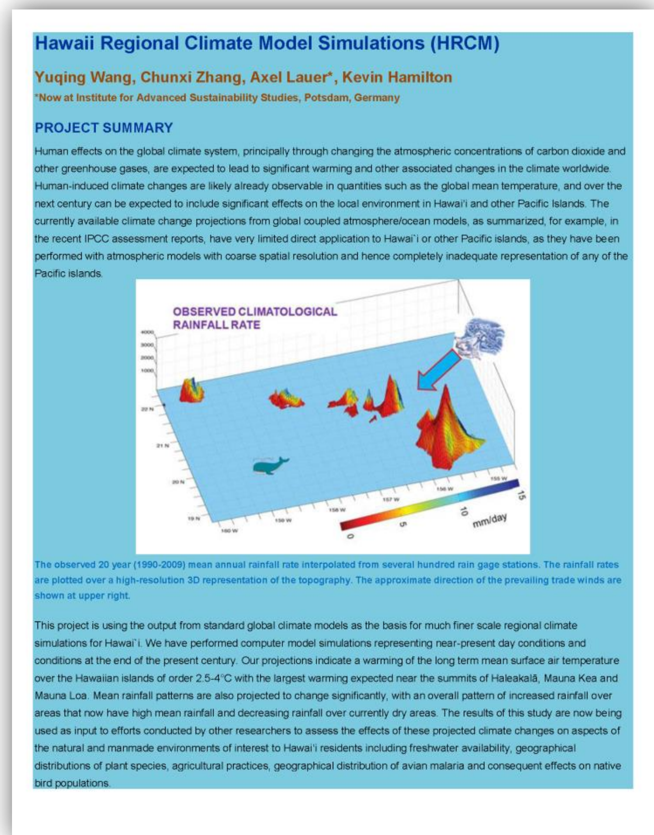
Elison Timm and others, 2015

Dynamical Approach



Hawaii Regional Climate Model Simulations (HRCM)

Yuqing Wang, Chunxi Zhang, Axel Lauer*, Kevin Hamilton

*Now at Institute for Advanced Sustainability Studies, Potsdam, Germany

PROJECT SUMMARY

Human effects on the global climate system, principally through changing the atmospheric concentrations of carbon dioxide and other greenhouse gases, are expected to lead to significant warming and other associated changes in the climate worldwide. Human-induced climate changes are likely already observable in quantities such as the global mean temperature, and over the next century can be expected to include significant effects on the local environment in Hawai'i and other Pacific Islands. The currently available climate change projections from global coupled atmosphere/ocean models, as summarized, for example, in the recent IPCC assessment reports, have very limited direct application to Hawai`i or other Pacific islands, as they have been performed with atmospheric models with coarse spatial resolution and hence completely inadequate representation of any of the Pacific islands.

The observed 20 year (1990-2009) mean annual rainfall rate interpolated from several hundred rain gage stations. The rainfall rates are plotted over a high-resolution 3D representation of the topography. The approximate direction of the prevailing trade winds are shown at upper right.

This project is using the output from standard global climate models as the basis for much finer scale regional climate simulations for Hawai`i. We have performed computer model simulations representing near-present day conditions and conditions at the end of the present century. Our projections indicate a warming of the long term mean surface air temperature over the Hawaiian islands of order 2.5-4°C with the largest warming expected near the summits of Haleakalā, Mauna Kea and Mauna Loa. Mean rainfall patterns are also projected to change significantly, with an overall pattern of increased rainfall over areas that now have high mean rainfall and decreasing rainfall over currently dry areas. The results of this study are now being used as input to efforts conducted by other researchers to assess the effects of these projected climate changes on aspects of the natural and manmade environments of interest to Hawai'i residents including freshwater availability, geographical distributions of plant species, agricultural practices, geographical distribution of avian malaria and consequent effects on native bird populations.

Zhang and others, 2012;
http://apdrc.soest.hawaii.edu/projects/HRCM/

Statistical Approach

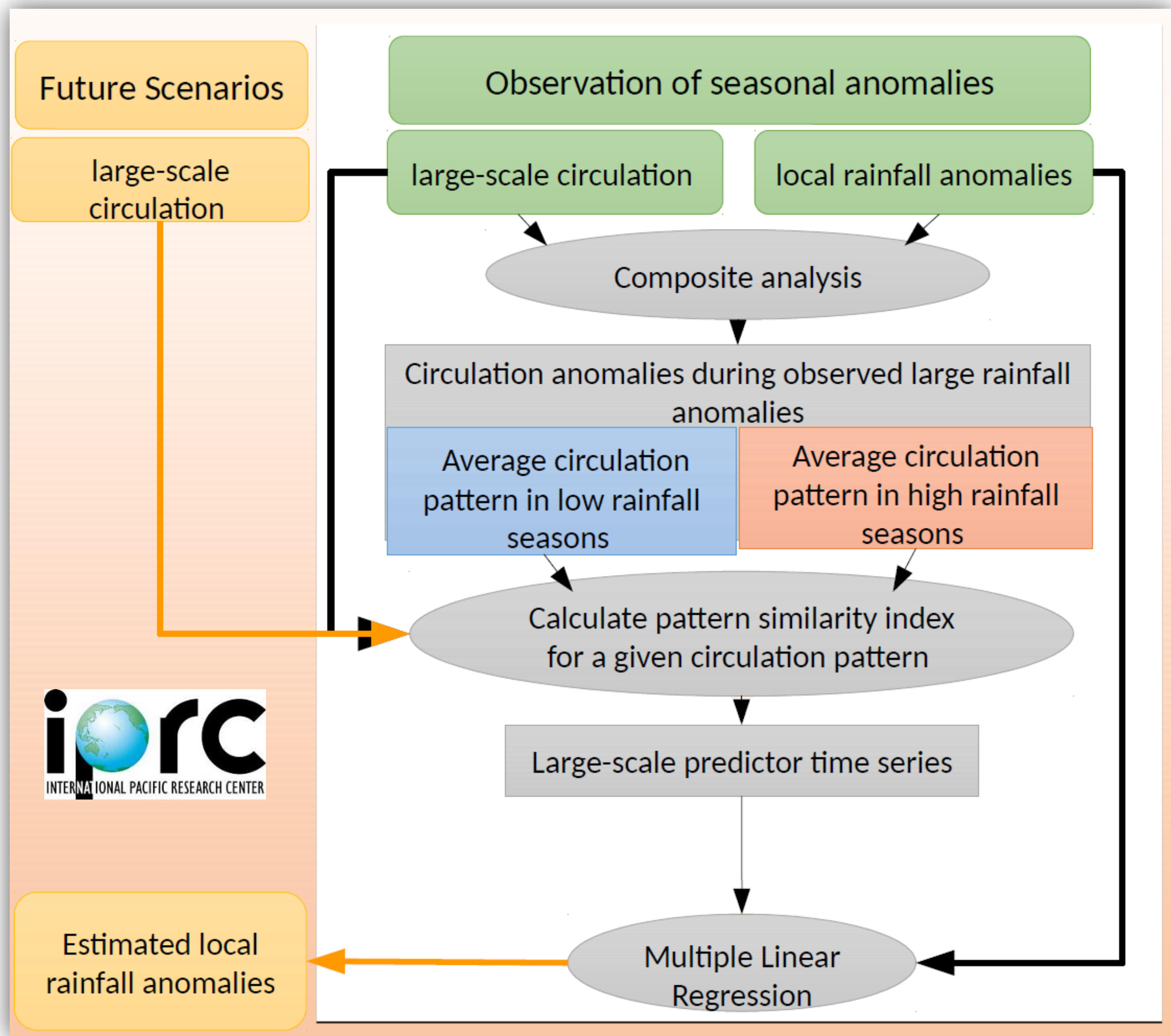


Figure from O.E. Timm

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Dynamical Approach

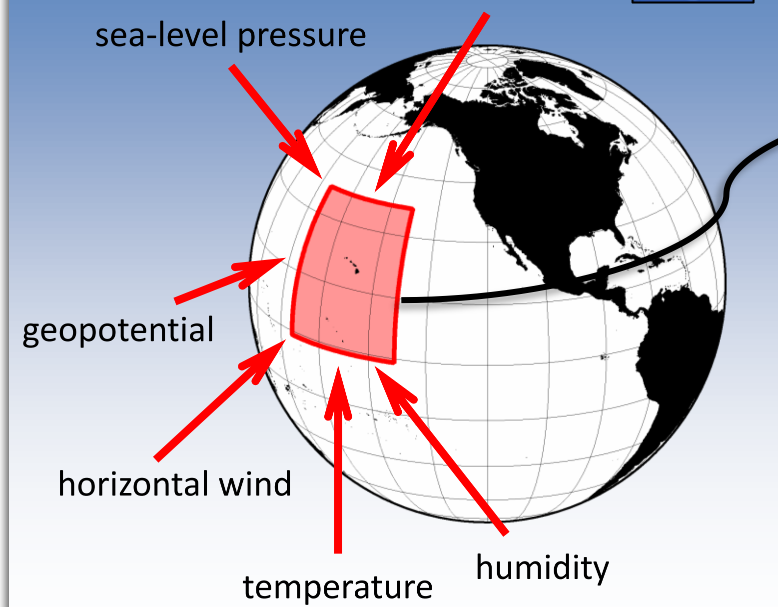
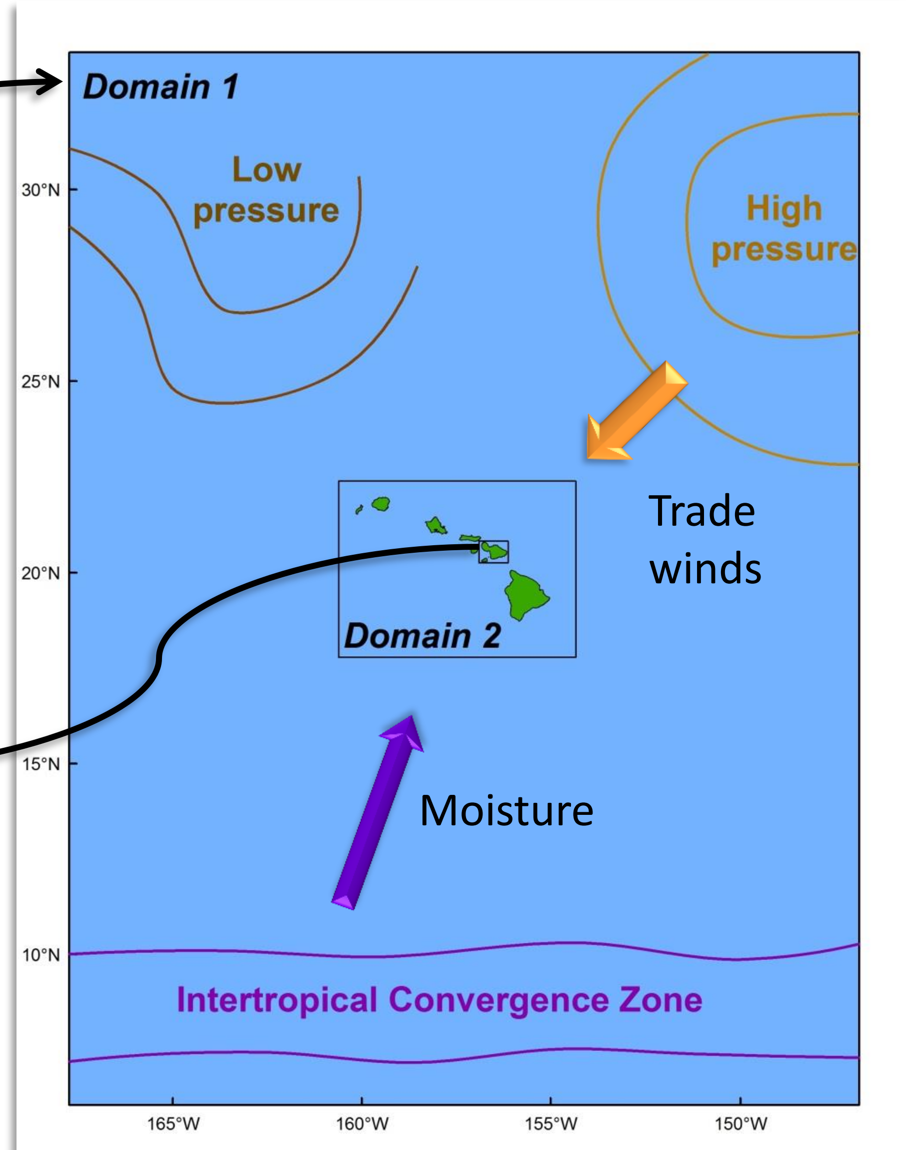
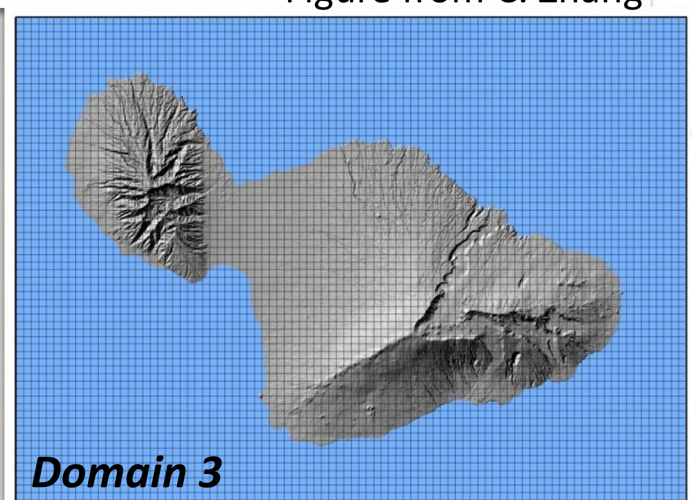


Figure from C. Zhang





Downscaled Climate Datasets

Feature	Statistical Approach	Dynamical Approach
Coupled Model Intercomparison Project (CMIP) Phase	Phase 5 (CMIP5)	Phase 3 (CMIP3)
Control Climate	Atlas mean monthly rainfall during 1978-2007	Simulated climate during 1990-2009
IPCC Scenario	Representative Concentration Pathway (RCP) 4.5 & 8.5	Special Report on Emissions Scenario (SRES) A1B
Projection Periods	2011-2041, 2041-2071, and 2071-2099	2080-2099

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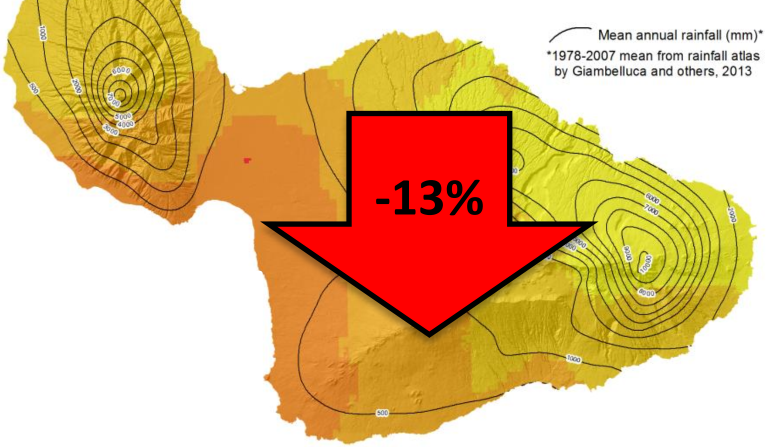
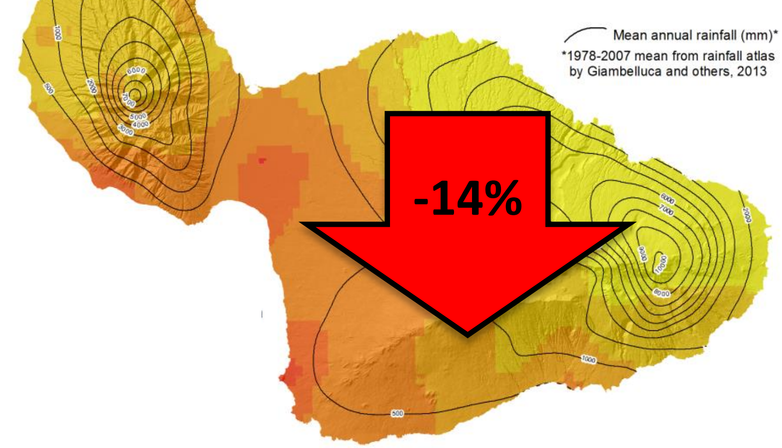
Statistical Approach – Mean Annual Rainfall Anomalies

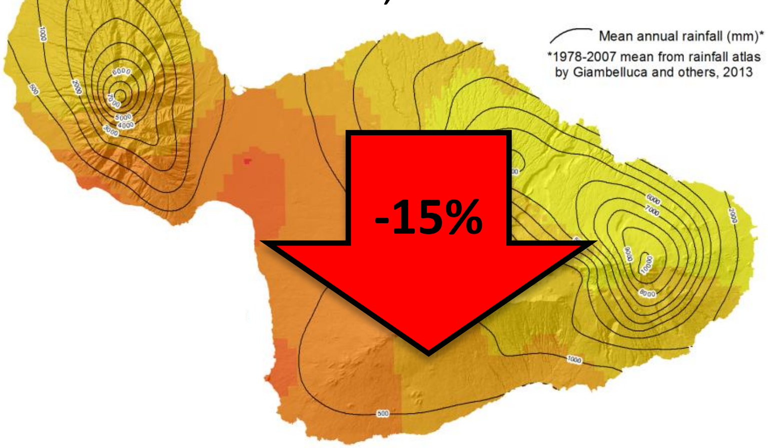
RCP4.5, 2041-71



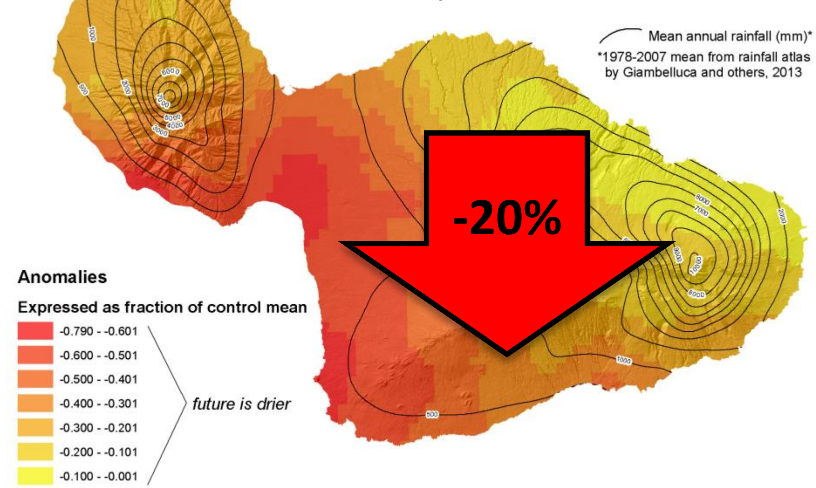
RCP8.5, 2041-71



RCP4.5, 2071-99



RCP8.5, 2071-99



Elison Timm and others, 2015;
250-m grid maps provided by O.E. Timm

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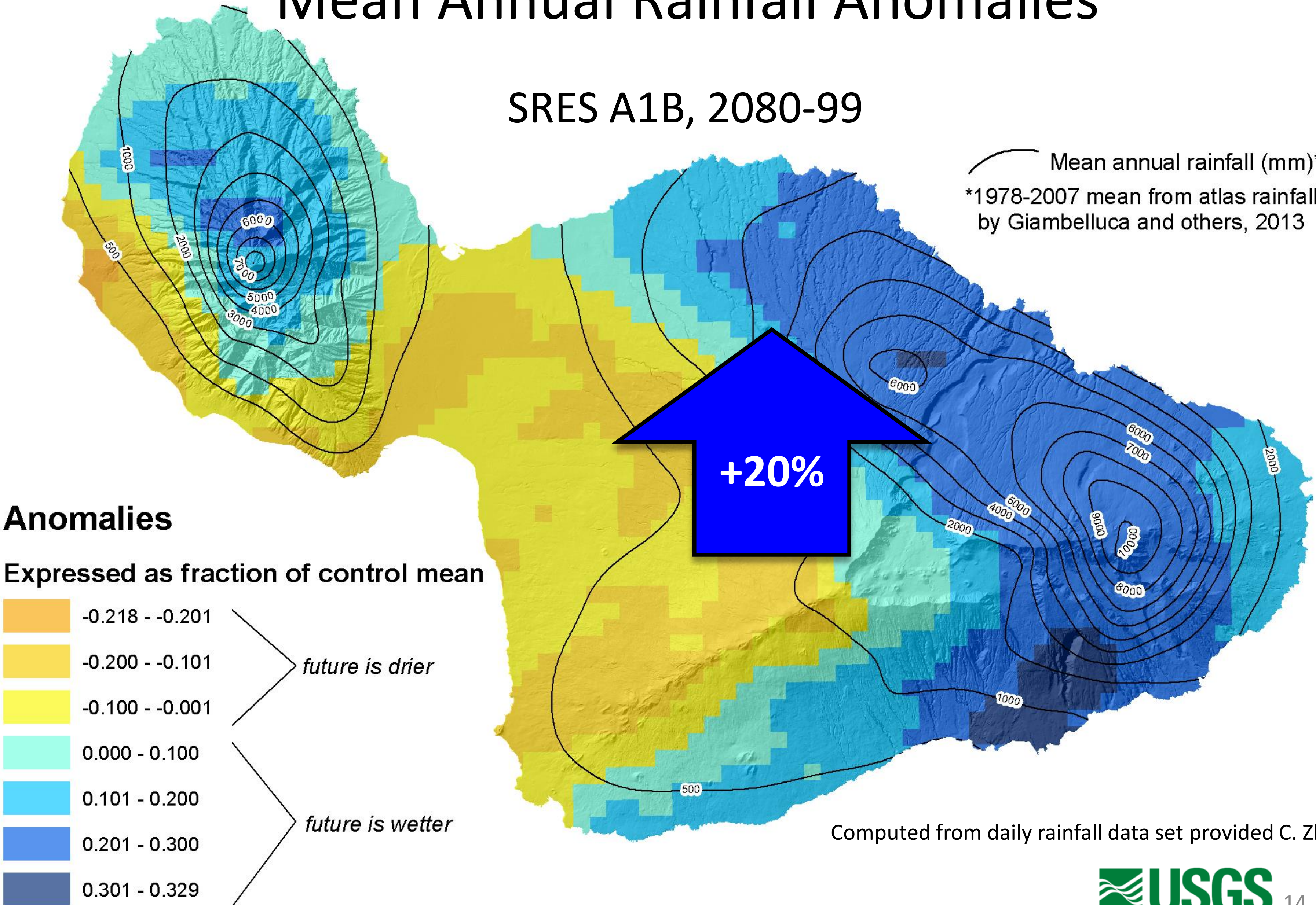
Dynamical Approach – Mean Annual Rainfall Anomalies



Computed from daily rainfall data set provided C. Zhang

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Which set of future rainfall projections should be used for water-resource planning?

- Statistical approach and dynamical approach show opposite changes in mean annual rainfall in many areas
- Simulating the driest and wettest rainfall conditions captures the range of uncertainty in existing set of climate projections

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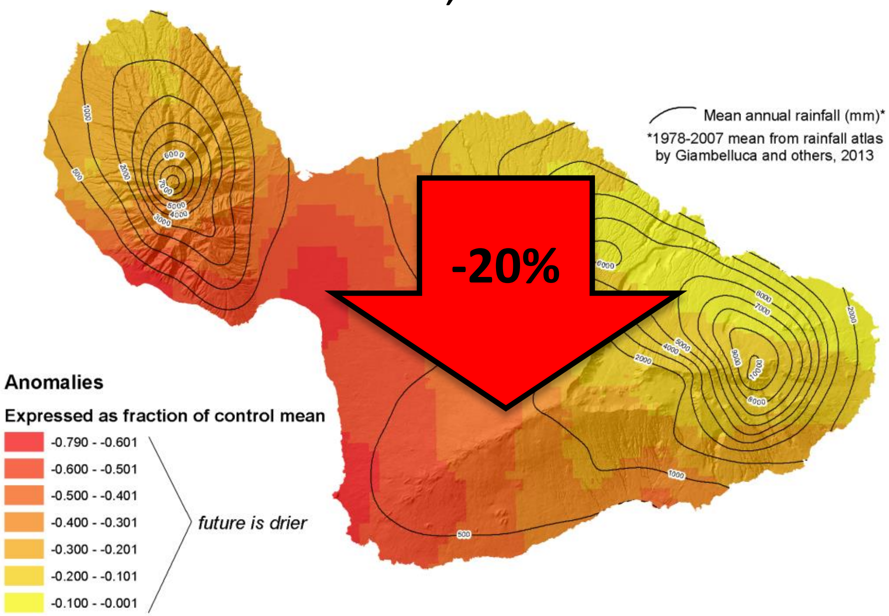
Selected Future Climate Scenarios

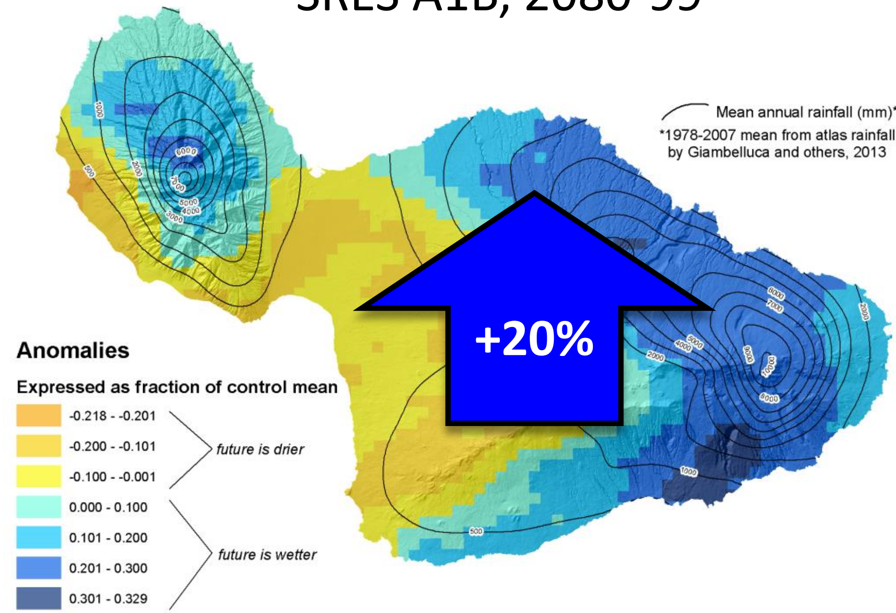
Projected
"Dry" Climate Scenario

Statistical Approach
RCP8.5, 2071-99



Projected
"Wet" Climate Scenario

Dynamical Approach
SRES A1B, 2080-99



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Other Challenges with Estimating and Comparing Hydrologic Impacts

- Issues related to dynamical approach
  - Represents only one emission scenario (SRES A1B)
  - Represents only one future time period (2080-2099)
  - Planning horizon for water managers typically less than 30 years
- Issues related to statistical approach
  - Method is not process-based
  - Does not provide all climatological elements needed for simulating water budget; independent estimates of future reference ET are needed
- Different control climate periods
  - Statistical approach uses 30-year period during 1978-2007
  - Dynamical approach uses 20-year period during 1990-2009

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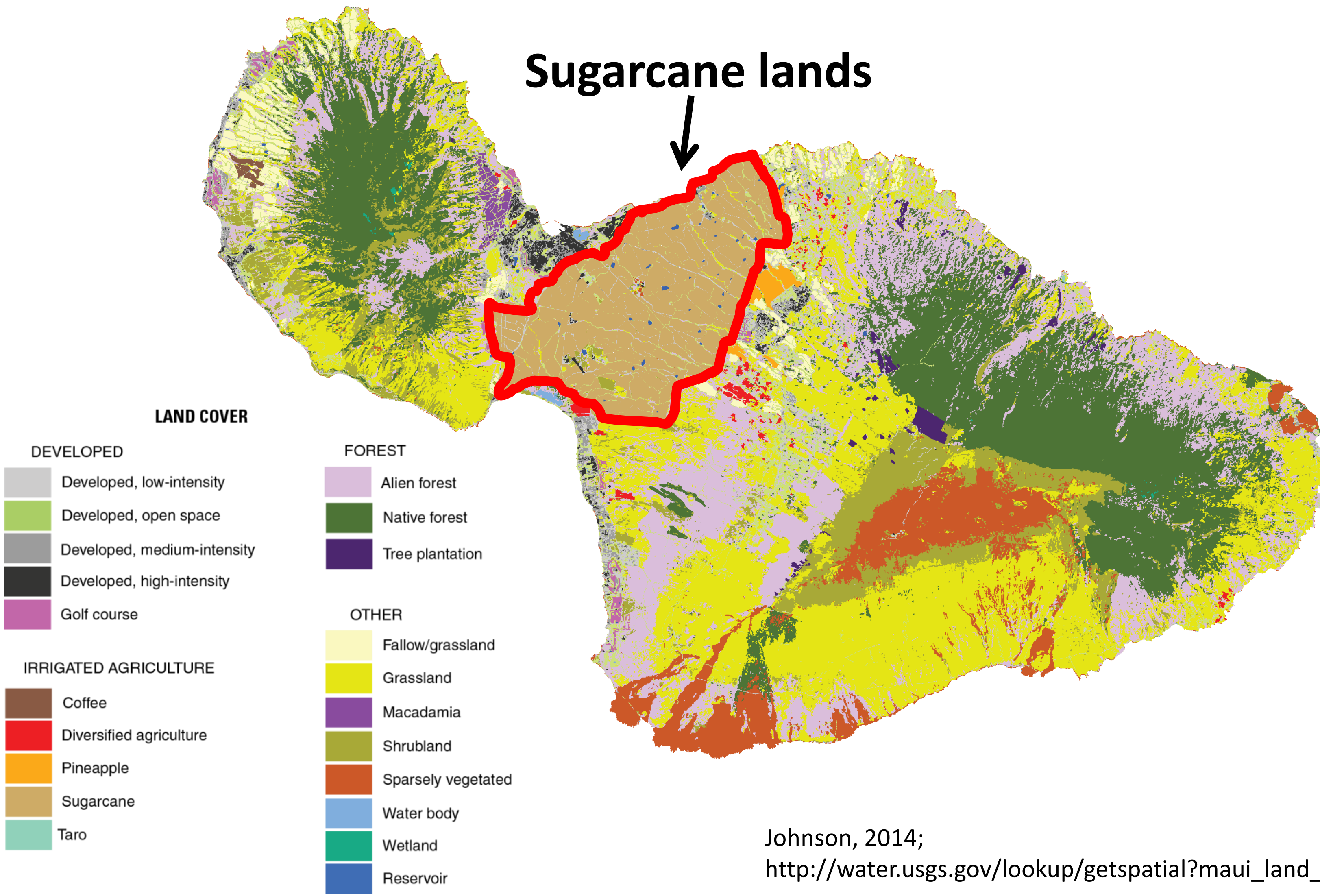
2010 Land Cover



Johnson, 2014;
http://water.usgs.gov/lookup/getspatial?maui_land_use_circa_2010

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Water-Budget Model Development

- Model developed for islands to estimate spatially distributed groundwater recharge
- Model has been applied in Hawai‘i, American Samoa, and Guam
- Required model input datasets:
  - Rainfall
  - Reference ET
  - Direct runoff
  - Land cover
  - Soil properties

These datasets are modified during climate-data transformation for estimating climate-change impacts

- Since 2005, model has been modified to accommodate improved rainfall and reference ET datasets, and more robust methods to estimate canopy interception, total ET, and direct runoff

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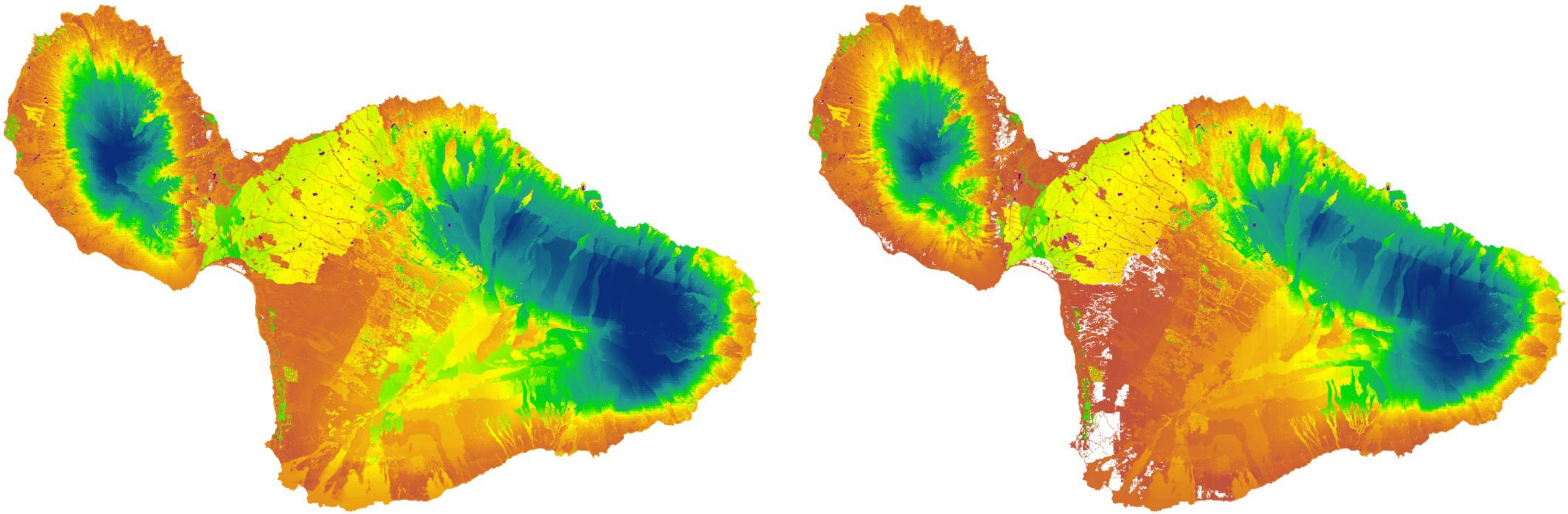
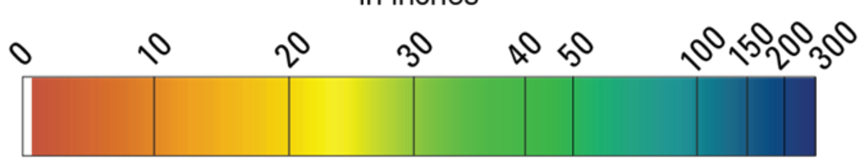
Groundwater Recharge Decreases by 21% for Projected Dry Climate Scenario

1978-2007 Climate

Statistical Approach
RCP8.5 2071-2099 Climate



Mean annual groundwater recharge, in inches



Areas where mean annual recharge is between 455 and 1,894 inches and includes taro fields and reservoirs

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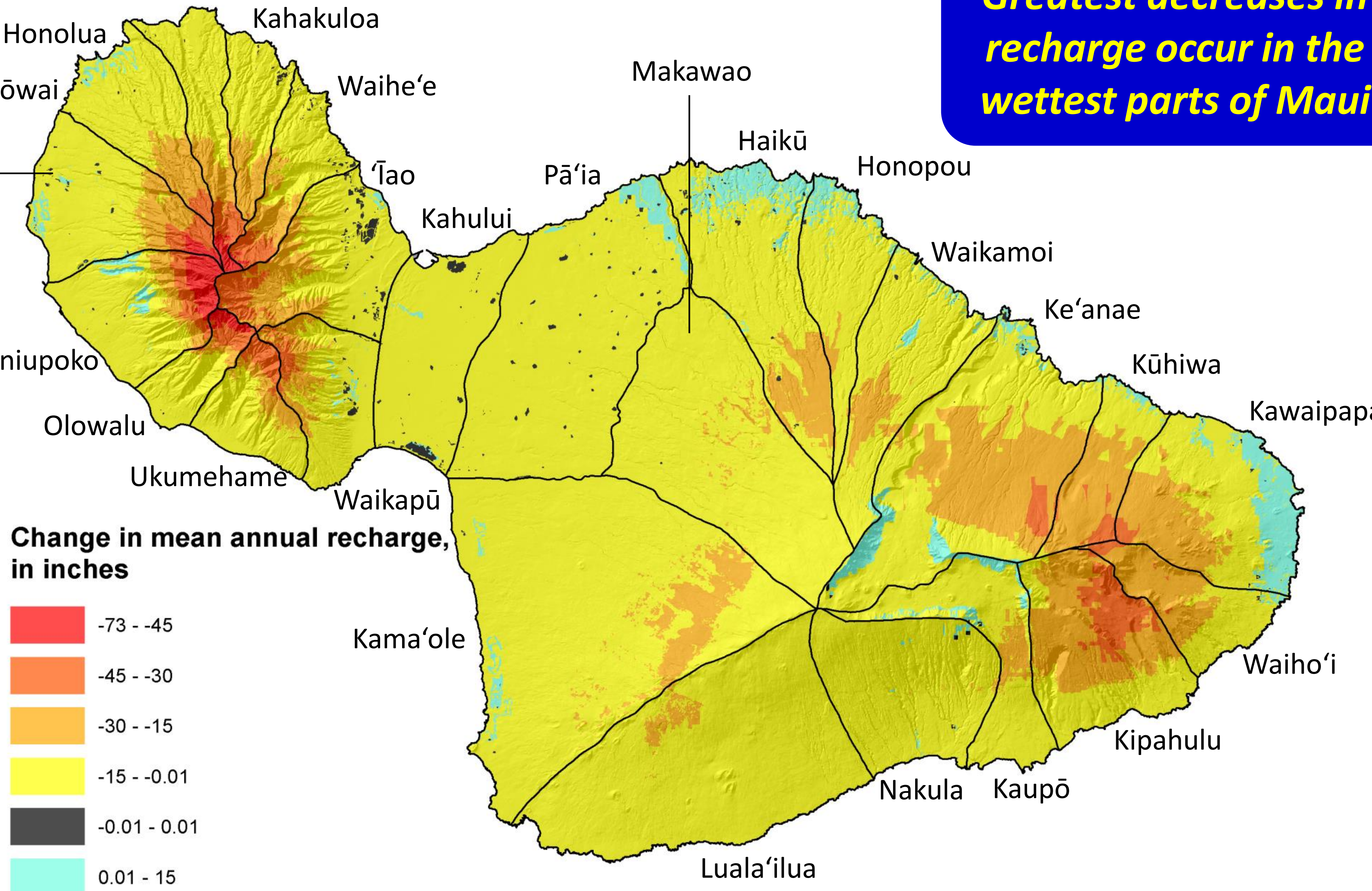
Change in Mean Annual Recharge for Projected Dry Climate Scenario

Greatest decreases in recharge occur in the wettest parts of Maui



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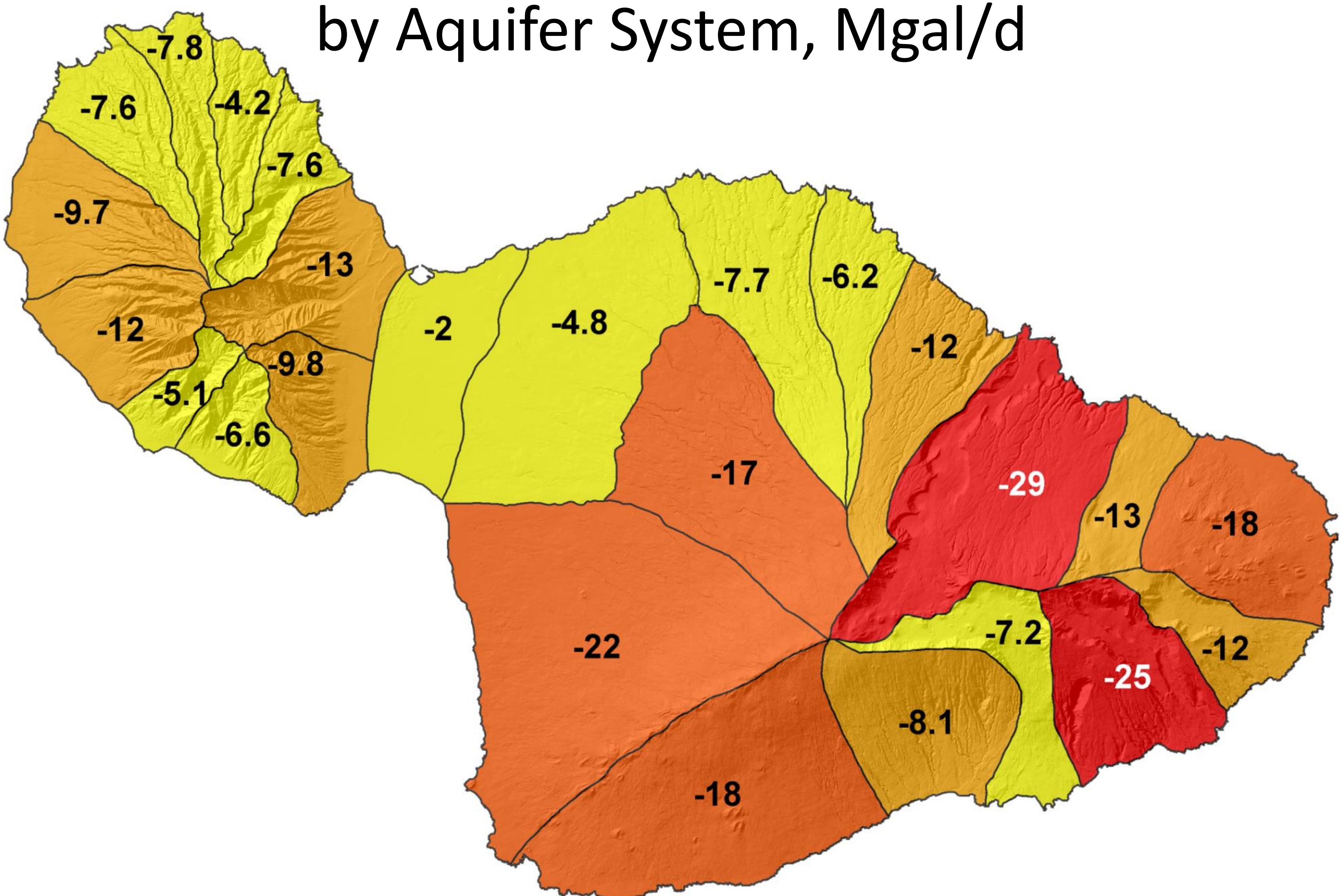
Change in Recharge by Aquifer System, Mgal/d



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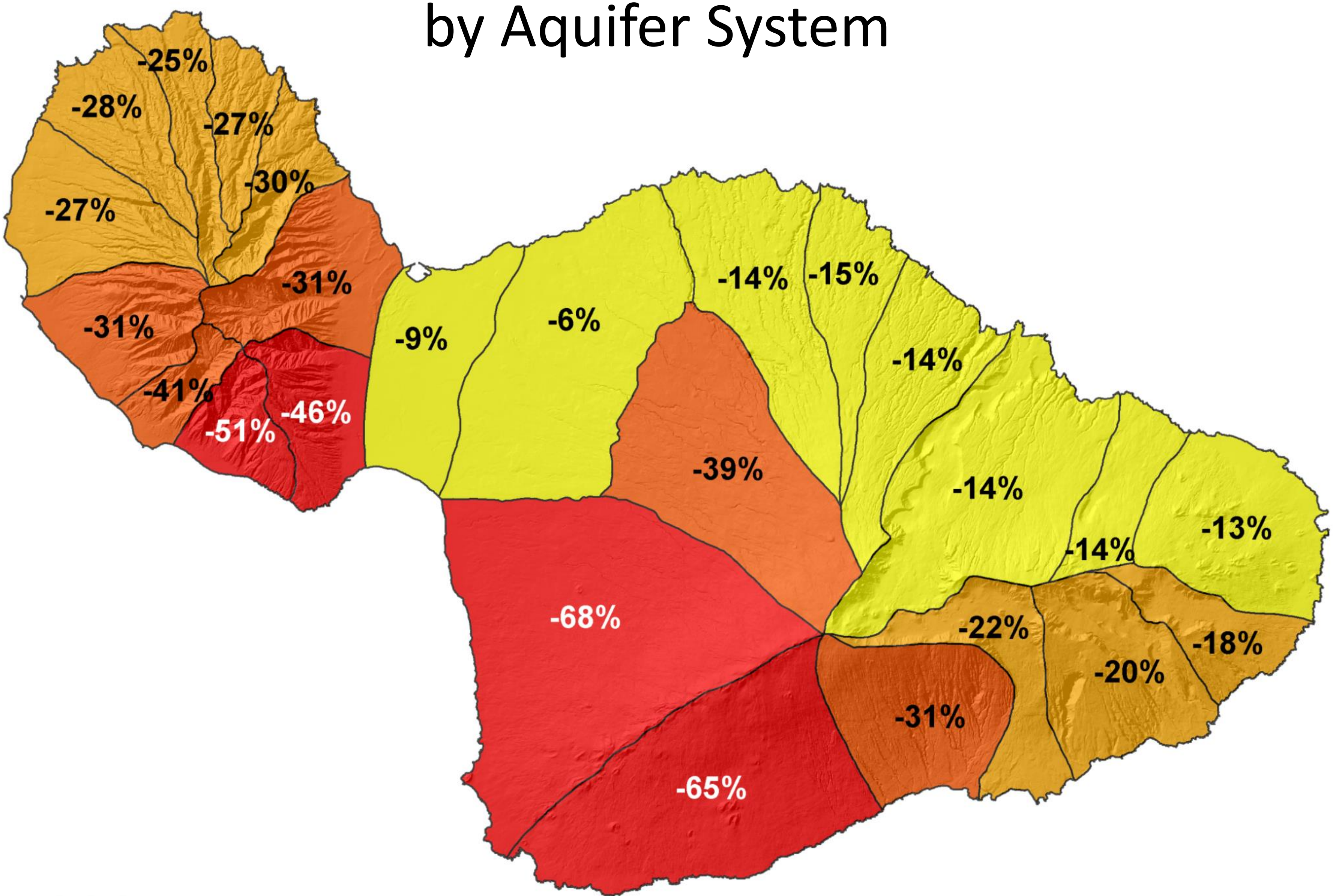
Percentage Change in Recharge by Aquifer System



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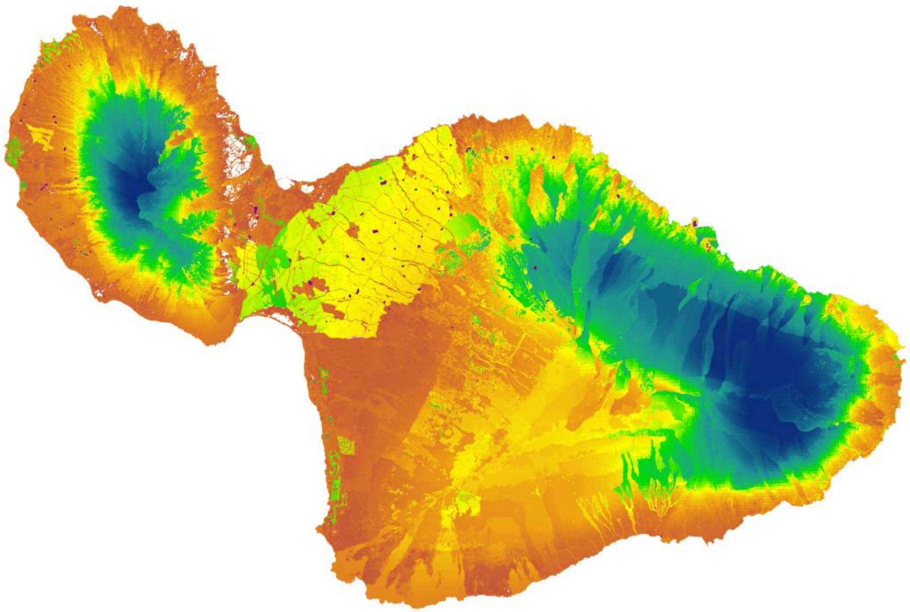
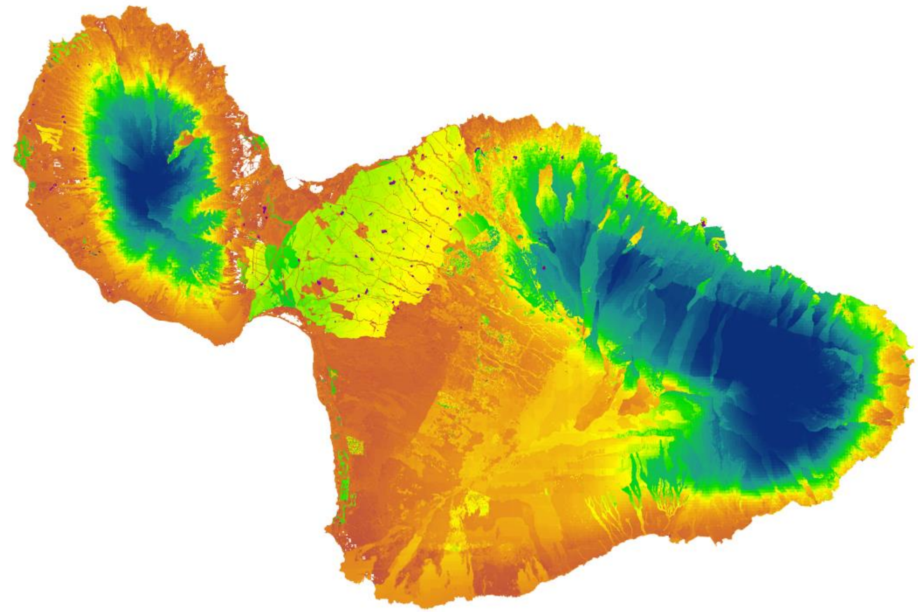
Groundwater Recharge Increases by 21% for Projected Wet Climate Scenario

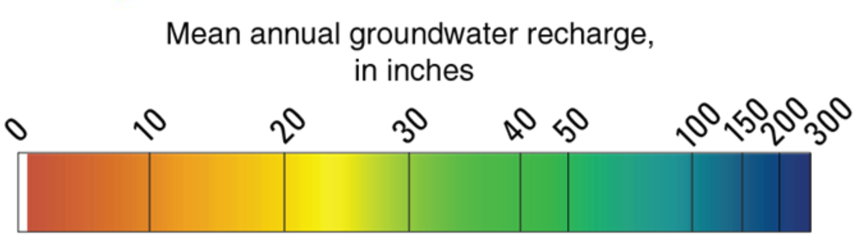
1990-2009 Climate



Dynamical Approach

SRES A1B 2080-2099 Climate

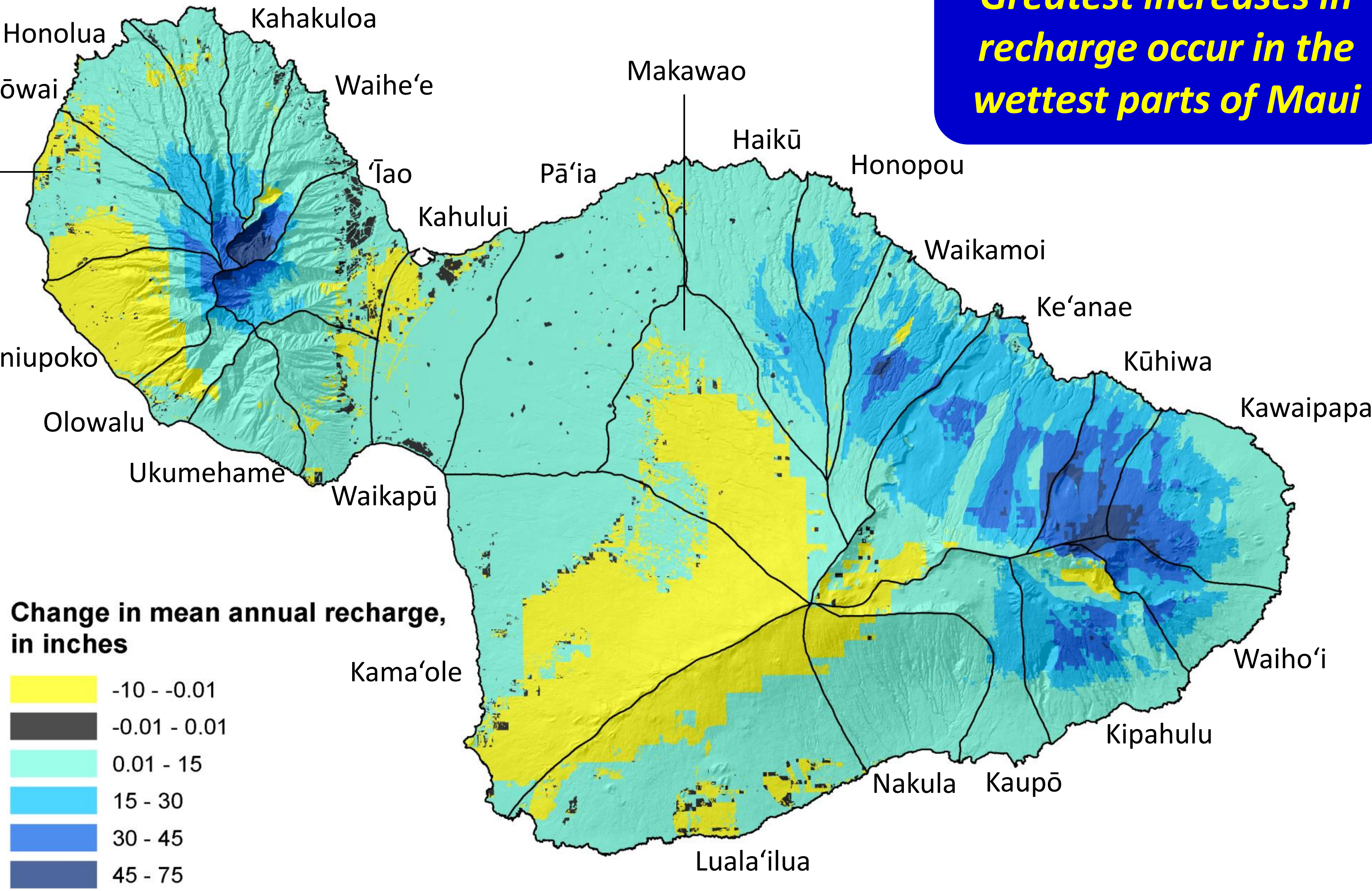




Areas where mean annual recharge is between 455 and 1,894 inches and includes taro fields and reservoirs

Change in Mean Annual Recharge for Projected Wet Climate Scenario

Greatest increases in recharge occur in the wettest parts of Maui



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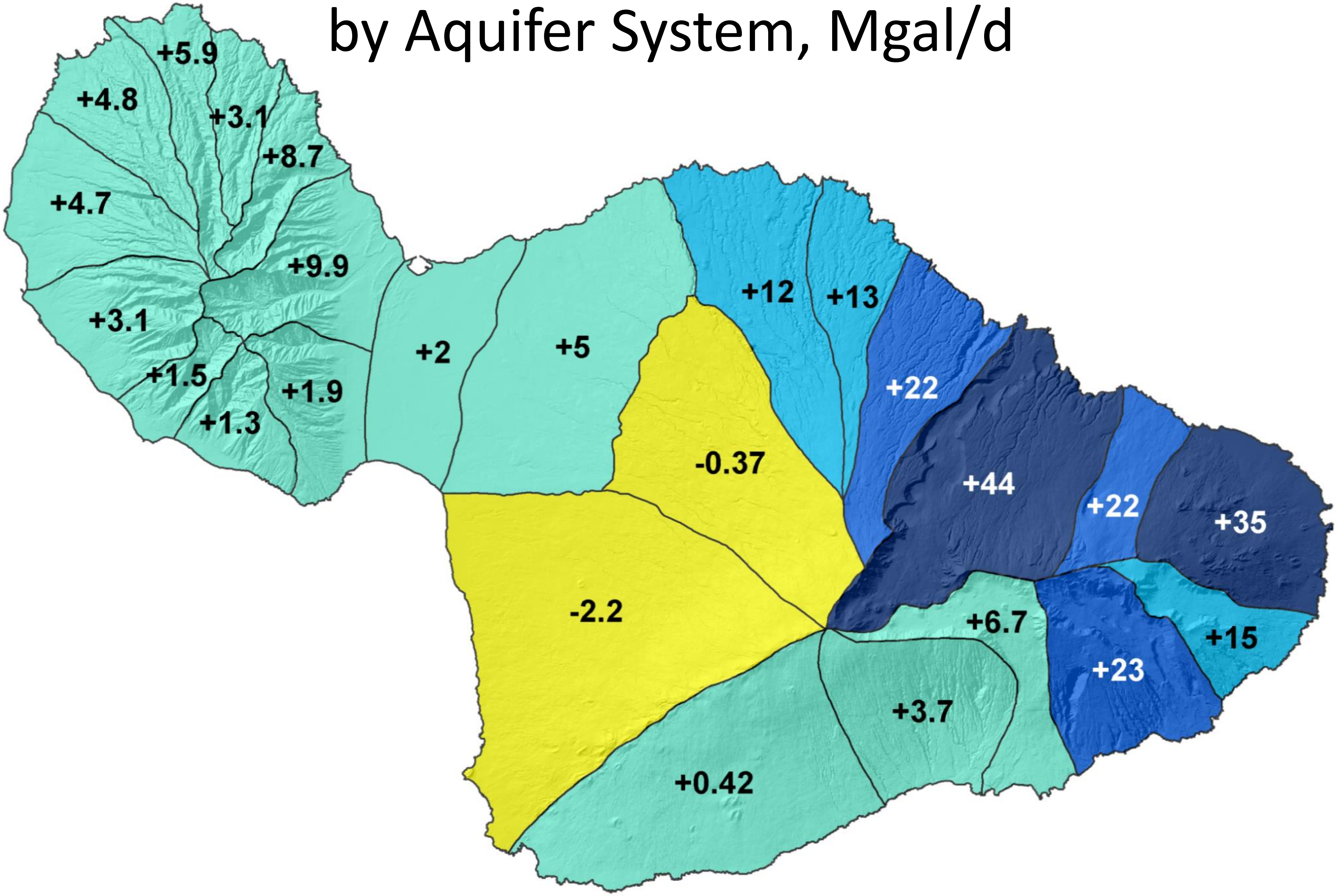
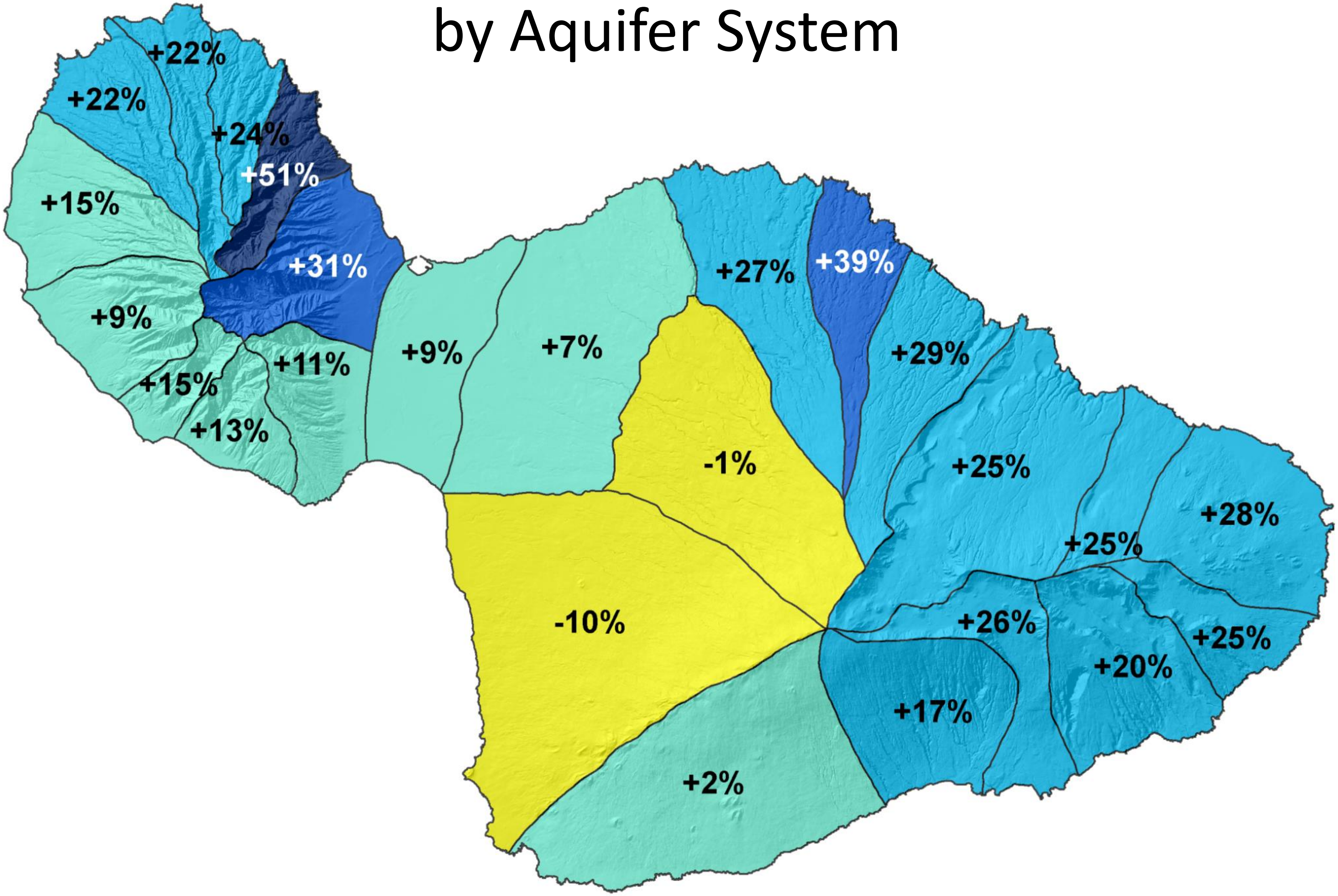
Change in Recharge by Aquifer System, Mgal/d



Percentage Change in Recharge by Aquifer System



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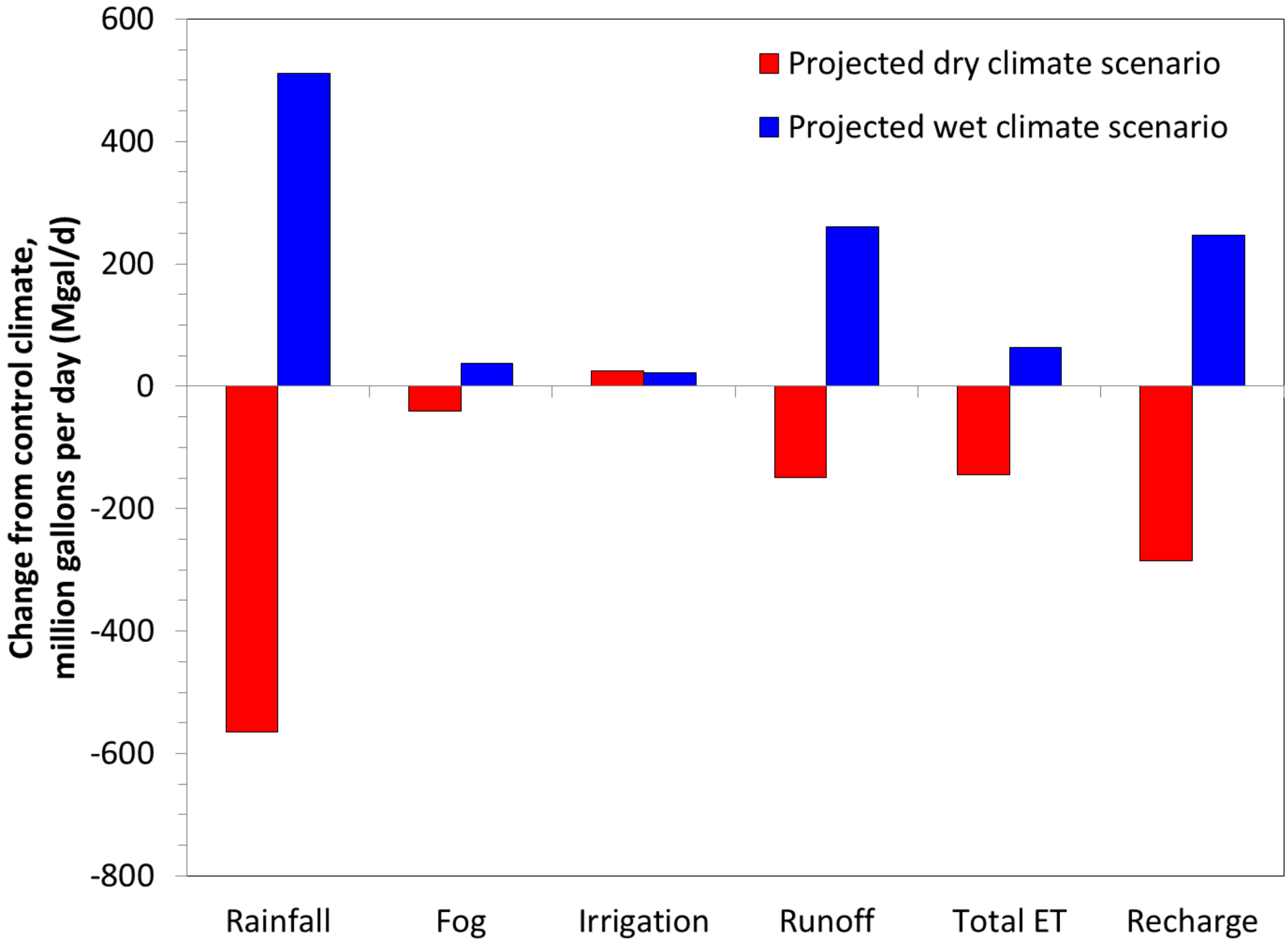
Island-Wide Comparison: Change in Mgal/d



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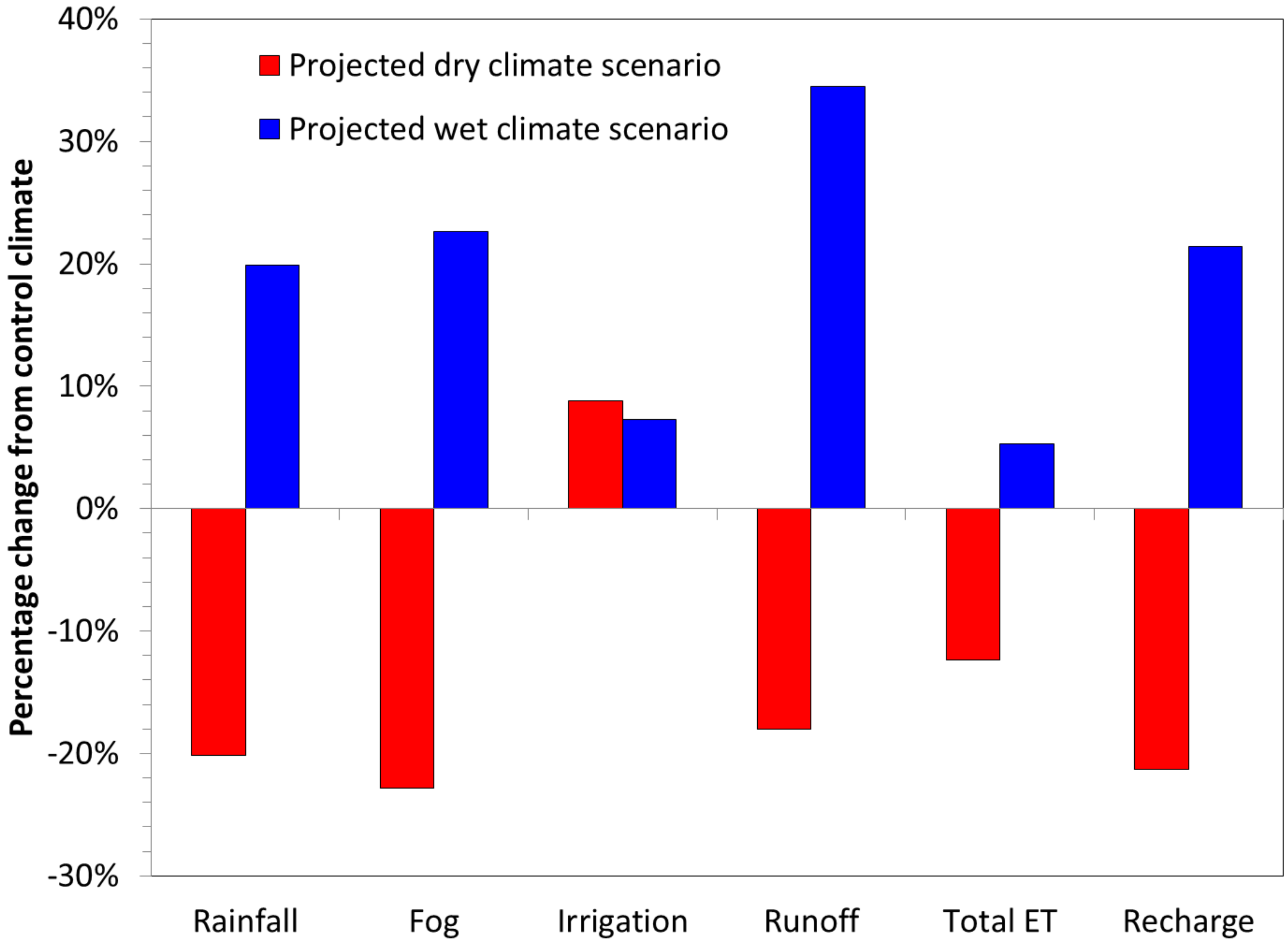
Island-Wide Comparison: Percentage Change



Preliminary Information—Subject to Revision.
Not for Citation or Distribution.

Summary for Maui

- Two existing projections indicate contrasting effects on estimated recharge across most of Maui
  - *Contrasting*: For ʻĪao and Waiheʻe aquifers, estimated changes to recharge vary from a **decrease** of 31% (ʻĪao) to an **increase** of 51% (Waiheʻe)
  - *Similar*: Both projections indicate a decline in recharge in Kamaʻole and Makawao aquifer systems
  - Estimated changes to island-wide recharge vary by plus or minus 21%
- Impacts to Kahului and Pāʻia aquifers are moderated by irrigation of sugar cane
- Greatest changes to recharge occur in west Maui mountains and wet windward areas of Haleakalā
- Uncertainty in climate projections likely will improve over time, which will lead to better-defined actionable science directions

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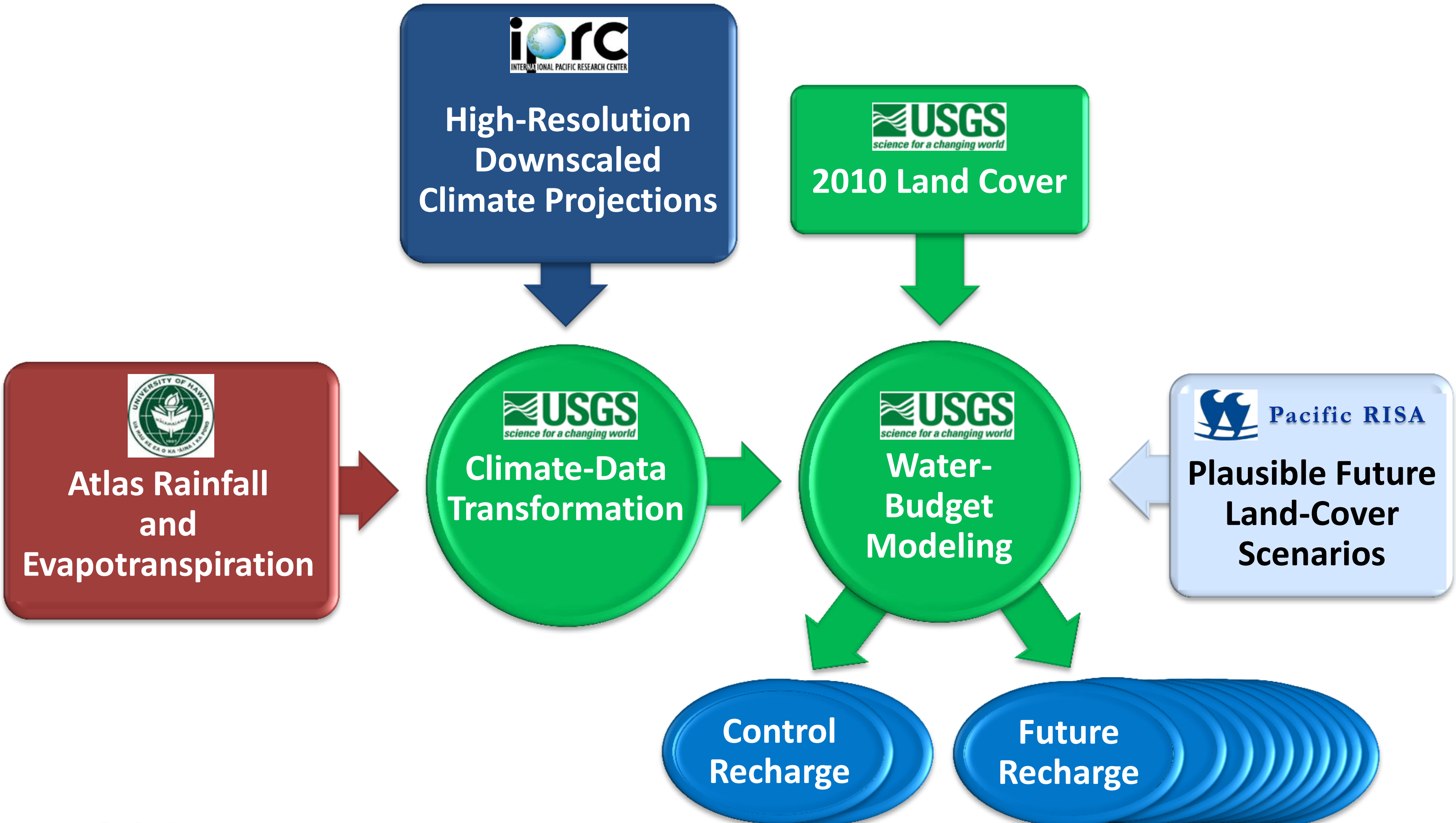
Next Steps – Water-Budget Modeling



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Next Steps – Publishing

- Publish estimated impacts to groundwater recharge for future climate/land-cover scenarios in scientific journal article
- Publish geospatial datasets presenting water-budget modeling results for each climate/land-cover scenario
  - USGS water resources NSDI node

Next Steps – Reducing Uncertainty

- Additional set of climate projections being developed for Hawai‘i by National Center of Atmospheric Research (NCAR)
  - Available by end of 2016 or early 2017
- Continued dialogue between climate scientists using statistical and dynamical downscaling approaches will lead to better understanding of differences in projections

Acknowledgments

- Chunxi Zhang, IPRC, University of Hawaiʻi at Mānoa
- Oliver Elison Timm, State University of New York at Albany
- Adam Johnson, USGS
- Maoya Bassiouni, Oregon State University
- Victoria Keener and Laura Brewington, Pacific RISA

QUESTIONS?

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